UNIT VI: POLLUTION (25–30%)

Areas on Which You Will Be Tested

A. Pollution Types

1. **Air pollution**—primary and secondary sources, major air pollutants, measurement units, smog, acid deposition—causes and effects, heat islands and temperature inversions, indoor air pollution, remediation and reduction strategies, Clean Air Act, and other relevant laws.
2. **Noise pollution**—sources, effects, and control measures.
3. **Water pollution**—types, sources, causes and effects, cultural eutrophication, groundwater pollution, maintaining water quality, water purification, sewage treatment/septic systems, Clean Water Act, and other relevant laws.
4. **Solid waste**—types, disposal, and reduction.

B. Impacts on the Environment and Human Health

1. **Hazards to human health**—environmental risk analysis, acute and chronic effects, dose-response relationships, air pollutants, smoking, and other risks
2. **Hazardous chemicals in the environment**—types of hazardous waste, treatment/disposal of hazardous waste, cleanup of contaminated sites, biomagnification, and relevant laws.

C. Economic Impacts—cost-benefit analysis, externalities, marginal costs, and sustainability.

Pollution

CHAPTER 9

It isn't pollution that's harming the environment. It's the impurities in our air and water that are doing it.

—Former U.S. Vice President Dan Quayle

AIR POLLUTION

Primary pollutants are emitted directly into the air from natural sources such as volcanoes, mobile sources such as cars, or stationary sources such as industrial smokestacks. Examples include: particulate matter or soot (PM_{10}), nitric oxide (NO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon dioxide (CO_2), and carbon monoxide (CO).

Secondary pollutants result from the reaction of primary pollutants in the atmosphere to form a new pollutant. Examples include sulfur trioxide (SO_3), sulfuric acid (H_2SO_4), ozone (O_3), and chemicals found in photochemical smog such as PANS and peroxyacyl nitrates.

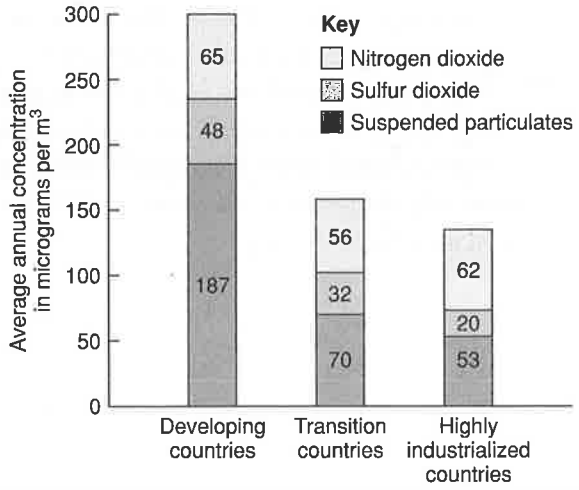


Figure 9.1 Particulate matter pollution in developing countries.
Source: World Resources Institute.

Major Air Pollutants

NITROGEN DIOXIDE (NO_2)

Forms when fuels are burned at high temperatures. Also results from forest fires, volcanoes, lightning, and bacterial action in soil. Forms nitric acid (HNO_3) in the air and contributes to acid deposition and cultural eutrophication. Results in lung irritation and damage, suppresses plant growth, and may be a carcinogen.

OZONE (O_3)

Major component of photochemical smog. Formed by sunlight reacting with NO_x and VOCs in the air. Causes lung irritation and damage, bronchial constriction, coughing, wheezing, and eye irritation. Damages plants, rubber, and plastics.

PEROXYACYL NITRATES (PAN)

PANs are secondary air pollutants formed from the reaction of various hydrocarbons combining with oxygen and nitrogen dioxide and being catalyzed by ultraviolet radiation from the sun: hydrocarbons + O_2 + NO_2 + light $\rightarrow$ $CH_3COOONO_2$ (PAN). Since they dissociate quite slowly in the atmosphere into radicals and NO_2, PANs are able to transport these unstable compounds far away from the urban and industrial origin. PANs transport NO_x to regions where it can more efficiently produce ozone. At concentrations of only a few parts per billion, they cause eye irritation. At higher concentrations, they cause extensive damage to vegetation.

SULFUR DIOXIDE (SO_2)

Produced by burning high-sulfur oil or coal, smelting of metals, and paper manufacturing. Combines with water vapor in the air to produce acid precipitation, which reduces the productivity of plants. Causes breathing difficulties. Significant decreases in concentrations and emissions in SO_2 concentration in the United States reflect the success of the Acid Rain Program and the Clean Air Act.

SUSPENDED PARTICULATE MATTER (PM_{10})

PM_{10}s are particles with a diameter 1/7 the width of a human hair or less (< 10 μm) and include smoke, dust, diesel soot, lead, and asbestos. PM_{10}s cause lung irritation and damage. Many are known mutagens, teratogens, and carcinogens. Reduction in PM_{10}s would produce health benefits 10 times greater than similar reductions in all other air pollutants combined.

VOLATILE ORGANIC COMPOUNDS (VOCs)

Include organic compounds that have a high vapor pressure. Over 600 compounds have been identified. Examples of VOCs include toluene, xylene, formaldehyde, benzene, and acetone. These are found in paints, aerosol sprays, dry-cleaning fluids, and industrial solvents. Causes respiratory irritation and damage. Most are carcinogenic and cause liver, kidney, and central nervous system damage. Concentration of VOCs may be 1,000 times higher indoors than outdoors.

Measurement Units

The most common form of expressing air pollutants is parts per million (ppm), which denotes one particle of a pollutant for every 999,999 particles of air. The symbol μ is often used to represent a millionth. This concentration is equivalent to one drop of ink in 40 gallons (150 L) of water or one second in 280 hours. To change ppm to a percentage, move the decimal place four places to the left and add a % sign. For example, a concentration of 400 ppm (0.04%) of carbon monoxide may be fatal. Two other common measurements are parts per billion (ppb or nano) and parts per trillion (ppt or pico).

Smog

There are two forms of smog: industrial smog and photochemical smog. Industrial smog tends to be sulfur-based and is also called grey-air smog. Photochemical smog is catalyzed by UV radiation and tends to be nitrogen-based. Photochemical smog is also called brown-air smog.

Formation of Industrial Smog

Step	Chemical Reaction
1. Carbon in coal or oil is burned in oxygen gas to produce carbon dioxide and carbon monoxide gas.	$C + O_2 \rightarrow CO_2$ $C + O_2 \rightarrow CO$
2. Unburned carbon ends up as soot or particulate matter (PM).	C
3. Sulfur in oil and coal reacts with oxygen gas to produce sulfur dioxide.	$S + O_2 \rightarrow SO_2$
4. Sulfur dioxide reacts with oxygen gas to produce sulfur trioxide.	$SO_2 + O_2 \rightarrow SO_3$
5. Sulfur trioxide reacts with water vapor in the air to form sulfuric acid.	$SO_3 + H_2O \rightarrow H_2SO_4$
6. Sulfuric acid reacts with atmospheric ammonia to form brown, solid ammonium sulfate.	$H_2SO_4 + NH_3 \rightarrow (NH_4)_2SO_4$

FORMATION OF PHOTOCHEMICAL SMOG

Net result: $NO + VOCs + O_2 + uv \rightarrow O_3 + PANs$

- **6 A.M.–9 A.M.**
  As people drive to work, concentrations of nitrogen oxides and VOCs increase:

$$N_2 + O_2 \rightarrow 2NO$$

$$NO + VOCs \rightarrow NO_2$$

$$NO_2 \xrightarrow{uv} NO + O$$

- **9 A.M.–11 A.M.**
  As traffic begins to decrease, nitrogen oxides and VOCs begin to react, forming nitrogen dioxide:

$$2NO + O_2 \rightarrow 2NO_2$$

- **11 A.M.–4 P.M.**
  As the sunlight becomes more intense, nitrogen dioxide is broken down and the concentration of ozone increases:

$$NO_2 \xrightarrow{uv} NO + O$$

$$O_2 + O \rightarrow O_3$$

  Nitrogen dioxide also reacts with water vapor to produce nitric acid and nitric oxide:

$$3NO_2 + H_2O \rightarrow 2HNO_3 + NO$$

  Nitrogen dioxide can also react with VOCs released by vehicles, refineries, gas stations, and so on to produce toxic PANs (peroxacyl nitrates):

$$NO_2 + VOCs \rightarrow PANs$$

- **4 P.M.–Sunset**
  As the sun goes down, the production of ozone is halted.

Acid Deposition—Causes and Effects

Acid rain is a broad term used to describe several ways that acids fall out of the atmosphere. A more precise term is acid deposition, which has two parts: wet and dry. Wet deposition refers to acidic rain, fog, and snow. As this acidic water flows over and through the ground, it affects a variety of plants and animals. The strength of the effects depends on many factors, including how acidic the water is, the chemistry and buffering capacity of the soils involved, and the types of organisms, such as fish, macroinvertebrates, trees, and other living things that rely on water and soil.

Dry deposition refers to acidic gases and particles. About half of the acidity in the atmosphere falls back to Earth through dry deposition. Wind blows these acidic particles and gases onto buildings, cars, homes, and trees. Dry-deposited gases and particles can also be washed from trees and other surfaces by rainstorms. When that happens, the runoff water adds those acids to the acid rain, making the combination more acidic than the falling rain alone.

Acid deposition due to sulfur dioxide (SO_2) begins with sulfur dioxide being introduced into the atmosphere by burning coal and oil, smelting metals, organic decay, and ocean spray. It then combines with water vapor to form sulfurous acid ($SO_2 + H_2O \rightarrow H_2SO_3$). Finally, the sulfurous acid reacts with oxygen to form sulfuric acid ($H_2SO_3 + \frac{1}{2}O_2 \rightarrow H_2SO_4$).

Acid deposition due to nitrogen oxides (NO_x) begins with nitrogen oxides formed by burning oil, coal, or natural gas. They also are found in volcanic vent gases and formed by forest fires, bacterial action in soil, and lightning-induced atmospheric reactions. Nitrogen monoxide, also known as nitric oxide (NO), reacts with oxygen gas to produce nitrogen dioxide gas ($NO + \frac{1}{2}O_2 \rightarrow NO_2$). Finally, nitrogen dioxide reacts with water vapor in the atmosphere to produce nitrous and nitric acids ($2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$).

Acid rain causes acidification of lakes and streams. It contributes to the damage of trees at high elevations and many sensitive forest soils through nitrogen saturation and creating acidic conditions that are unhealthy for decomposers and mycorrhizal fungi. Acid shock, which is caused by the rapid melting of snow pack that contains dry acidic particles, results in acid concentrations in lakes and streams 5 to 10 times higher than acidic rainfall. In addition, acid rain accelerates the decay of building materials and paints, including irreplaceable statues and sculptures. Acid rain also leaches essential plant nutrients from the soil such as Ca^{2+}, K^{+} and Mg^{2+}. Heavy metal ions such as Pb^{2+}, Cd^{2+}, and Hg^{2+} that are contained within rock structures may be leached out of the rocks and into the soil structure. Prior to falling to Earth, SO_2 and NO_x gases and their particulate matter derivatives (sulfates and nitrates) contribute to breathing difficulties and other health matters.

Heat Islands and Temperature Inversions

Urban heat islands occur in metropolitan areas that are significantly warmer than their surroundings. Urban air can be 10°F (6°C) warmer than the surrounding area. Since warmer air can hold more water vapor, rainfall can be as much as 30% greater downwind of cities when compared with areas upwind. One of the main reasons for higher-than-normal nighttime air temperatures in urban areas are buildings that reduce the radiation of urban heat to the night sky. Thermal properties of surface materials (bricks, concrete, and asphalt) store heat longer. The lack of vegetation and standing water in many urban areas also increase urban temperatures. The canyon effect results from buildings reflecting and absorbing heat and blocking winds that reduce heat through convection. Human activities that increase the heat island effect include the operation of automobiles, air conditioners, and industry. Since demand for air-conditioning rises during summer months, problems associated with energy availability and pricing become compounded.

High levels of pollution in urban areas can also create a localized greenhouse effect. Urban heat islands can directly influence the health and welfare of urban residents who cannot afford air-conditioning. As many as 1,000 people per year die in the United States due to excessive temperatures. Urban heat islands can produce secondary effects on local meteorology, including the altering of local wind patterns, the development of clouds and fog, the number of lightning strikes, and the rate of precipitation. The heat island effect can be slightly reduced by using white or reflective building materials and increasing the amount of landscaping and parks.

Temperature inversions occur when air temperature increases with height above the ground, as opposed to the normal decrease in temperature with height. This effect can lead to pollution such as smog being trapped close to the ground, with possible adverse effects on human health (asthma, emphysema, and increases in lung cancer). Temperature inversions commonly occur at night when solar heating ceases and the surface cools, which then cools the atmosphere immediately above it.

A warm air mass then moving over a colder one keeps the cooler air mass trapped below, and the air becomes still. This results in dust and pollutants being trapped and their concentrations increasing. A nearly permanent temperature inversion occurs over Antarctica.

CASE STUDY

In 1948, 20 people were asphyxiated and over 7,000 were hospitalized or became ill as the result of severe air pollution over Donora, PA, a town of 14,000. Smog from the local zinc and steel smelting plants settled in the valley where the town was located. Four days later, winds finally cleared the toxins from the town. The investigation of this incident by state and federal health officials resulted in the first meaningful federal and state laws to control air pollution and marked the beginning of modern efforts to assess and deal with the health threats from air pollution.

Indoor Air Pollution (Sick Building Syndrome)

Many people spend the majority of their lives indoors sleeping, working, eating, and relaxing, where air circulation may be restricted and where indoor air pollutant levels may be 25% to 60% greater than outdoor levels. Sick building syndrome (SBS) is a term used to describe a combination of ailments (a syndrome) associated with an individual's place of work or residence. Up to a third of new and remodeled buildings worldwide may be linked to symptoms of SBS. The most common pollutants found indoors include molds, bacteria, carbon monoxide, radon, allergens, asbestos, tobacco smoke, and formaldehyde and other volatile organic compounds (VOCs) released from carpeting, adhesives, and particleboard. SBS is frequently pinned down to flaws in heating, ventilation, and air conditioning (HVAC) systems. Symptoms of indoor air pollution can range from headaches, breathing difficulties, and allergies to asthma, cancer, emphysema, and various nerve disorders.

Remediation and Reduction Strategies

Strategies designed to improve air quality in general include:

1. Emphasizing tax incentives for pollution control rather than fines and penalties
2. Setting legislative standards for energy efficiency
3. Increasing funding for research into renewable energy sources
4. Incorporating incentives for reducing air pollution into trade policies
5. Distributing solar cookstoves to developing countries to replace coal and firewood
6. Phasing out two-cycle gasoline engines
7. For issues involving sick building syndrome: (a) modify building codes to control materials used in construction; (b) replace and repair areas that have received water damage in order to control mold (carpeting, ceiling tiles, inside walls, etc.); (c) use paints, adhesives, solvents, cleaning products, and pesticides in well-ventilated areas and during periods of non-occupancy; (d) increase the number of complete air exchanges in the building; and (e)

ensure proper maintenance of HVAC systems, including the use of UVC in such systems.

8. Providing incentives to use mass transit

Several strategies have been designed to reduce the effects of acid rain. They include designing more efficient engines to reduce NO_x emissions and increasing the efficiency of coal-burning plants to reduce SO_2, NO_x, and particulates through washing coal and using scrubbers, advanced filtration on smokestacks, electrostatic precipitators, and staged and catalytic burners with afterburners. Other strategies include increasing penalties on stationary sources that do not reduce emissions, providing tax incentives to companies that do reduce pollutants, providing incentives to consumers to purchase Energy Star appliances and products that conserve energy, and increasing CAFE standards.

The EPA's Acid Rain Program is designed to achieve significant environmental and public health benefits through reductions in emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x), the primary causes of acid rain. To achieve this goal at the lowest cost to society, the program employs both traditional and innovative market-based approaches for controlling air pollution. In addition, the program encourages energy efficiency and pollution prevention. Specific strategies employed include an allowance trading system, an opt-in program that allows nonaffected industrial and small utility units to participate in allowance trading, setting new NO_x emissions standards for existing coal-fired utility boilers, and allowing emissions averaging to reduce costs. Another is a permit process that affords sources maximum flexibility in selecting the most cost-effective approach to reducing emissions. Continuous emission monitoring (CEM) requirements provide credible accounting of emissions to ensure the integrity of the market-based allowance system and to verify the achievement of the reduction goals. The excess emissions provision provides incentives to ensure self-enforcement. Another strategy is an appeals procedure that allows the regulated community to appeal decisions with which it may disagree.

The Clean Air Act was originally signed into law in 1963. Its goal was to protect public health from air pollution and limit the effects of air pollution on the environment. Early versions allowed individual states to set their own standards. Later versions of the act switched responsibility of setting uniform standards to the federal government. Primary standards protect human health. Secondary standards protect materials, crops, climate, visibility, and personal comfort. The 1990 version addressed acid rain, urban smog, air pollutants, ozone protection, marketing pollution rights, and VOCs. Estimates are that the Clean Air Act is responsible each year for saving 15,000 lives, reducing bronchitis cases by 60,000, and reducing 9,000 hospital admissions due to respiratory illnesses. The following chart shows some of the progress that the Clean Air Act has been responsible for since it was passed into law. Notice however, the increase in PM_{10} and NO_x levels.

Pollutant	% Change
Pb	–98%
VOC	–42%
SO_2	–37%
CO	–31%
NO_x	+17%
PM_{10}	+266 %

The 1997 Kyoto Protocol would have required the United States to reduce greenhouse emissions by 7% when compared with 1990 levels over a five-year period. Under this agreement, the United States would have faced penalties if it did not meet its emission cuts. The United States saw this as an unattainable target since carbon dioxide and greenhouse gases continue to increase and are projected to increase for the next 20 years. The United States felt that the protocol held developed nations responsible for meeting the cuts but did not apply the same standards to developing nations. Reasons given for not agreeing with the rest of the signing members of the Kyoto Protocol were the cost of meeting the emission targets would be too high, the time frame was too short for implementation, and there was no evidence of a correlation between greenhouse gases and global warming.

RELEVANT LAWS AND PROTOCOLS

Air Pollution Control Act (1955): The nation's first piece of federal legislation regarding air pollution. Identified air pollution as a national problem and announced that research and additional steps to improve the situation needed to be taken. It was an act to make the nation more aware of this environmental hazard.

Clean Air Act (1963): Dealt with reducing air pollution by setting emissions standards for stationary sources such as power plants and steel mills. It did not take into account mobile sources of air pollution, which had become the largest source of many dangerous pollutants. It also set standards for auto emissions, expanded local air pollution control programs, established air quality control regions (AQCR), set air quality standards and compliance deadlines for stationary source emissions, and authorized research on low-emissions fuels and automobiles.

National Environmental Policy Act (1969): Requires a systematic analysis of major federal actions. Includes a consideration of all reasonable alternatives as well as an analysis of short-term and long-term, irretrievable, irreversible, and unavoidable impacts.

Clean Air Act (1970): Established new primary and secondary standards for ambient air quality, set new limits on emissions from stationary and mobile sources to be enforced by both state and federal governments, and increased funds for air pollution research. It was soon discovered that the deadlines set were overly ambitious (especially those for auto emissions). To reach these standards in such a short period of time, the auto industry faced serious economic limitations and seemingly insurmountable technological challenges. Over the next decade, the legislation was once again amended to extend these deadlines and to mandate states to revise their implementation plans.

Montreal Protocol (1989): An agreement among nations requiring the phaseout of chemicals that damage the ozone layer.

Clean Air Act (1990): Addressed five main areas: air quality standards, motor vehicle emissions and alternative fuels, toxic air pollutants, acid rain, and stratospheric ozone depletion.

Pollution Prevention Act (1990): Requires industries to reduce pollution at its source. Reduction can be in terms of volume and/or toxicity.

Kyoto Protocol (1997 and 2001): An agreement among 150 nations requiring greenhouse gas reductions.

NOISE POLLUTION

Noise pollution is unwanted human-created sound that disrupts the environment. The dominant form of noise pollution is from transportation sources, principally motor vehicles, aircraft noise, and rail transport noise. Besides transportation noise, other prominent sources are office equipment, factory machinery, appliances, power tools, and audio entertainment systems. Noise regulation by governmental agencies effectively began in the United States with the 1972 Federal Noise Control Act.

Effects

Normal hearing depends on the health of the inner, middle, and outer ear. Three kinds of hearing loss occur: conductive, sensory, and neural. Sensory hearing loss is caused by damage to the inner ear and is the most common form associated with noise.

In addition to contributing to hearing loss, too much noise can affect health in other ways too. Immediate effects may be temporary or may become permanent. They may include cardiovascular problems with an accelerated heartbeat and high blood pressure, gastric-intestinal problems, a decrease in alertness and ability to memorize, nervousness, pupil dilation, and a decrease in the visual field. Effects that may be longer lasting include insomnia, nervousness, bulimia, chronically high blood pressure, anxiety, depression, and sexual dysfunction.

Control Measures

Roadway noise can be reduced through the use of noise barriers, limitations on vehicle speed, newer roadway surface technologies, limiting times for heavy-duty vehicles, computer-controlled traffic flow devices that reduce braking and acceleration, and changes in tire design. Aircraft noise can be reduced through developing quieter jet engines and rescheduling takeoff and landing times. Industrial noise can be reduced through new technologies in industrial equipment and installation of noise barriers in the workplace. Residential noise such as power tools, garden equipment, and loud radios can be controlled through local laws and enforcement.

RELEVANT LAW

Noise Control Act (1972): Establishes a national policy to promote an environment for all Americans free from noise that jeopardizes their health and welfare. To accomplish this, the act establishes a means for the coordination of federal research and activities in noise control, authorizes the establishment of federal noise emissions standards for products distributed in commerce, and provides information to the public respecting the noise emission and noise reduction characteristics of such products.

WATER POLLUTION

Water pollution can originate from either a point or a nonpoint source. A point source occurs when harmful substances are emitted directly into a body of water. An example of a point source of water pollution is a pipe from an industrial facility discharging effluent directly into a river. Point source pollution is usually monitored and regulated in developed countries.

Nonpoint sources deliver pollutants indirectly through transport or environmental change. An example of a nonpoint source of water pollution is when fertilizer from a farm field is carried into a stream by rain (run off). Nonpoint sources are much more difficult to monitor and control, and they account for the majority of contaminants in streams and lakes.

Sources of Water Pollution

The following sections describe the varied sources of water pollution. They include air pollution, chemicals, microbiological sources, mining, noise, nutrients, oxygen-depleting substances, suspended matter, and thermal sources.

AIR POLLUTION

Pollutants like mercury, sulfur dioxide, nitric oxides, and ammonia fall out of the air and into the water. They can then cause mercury contamination in fish and acidification and eutrophication of lakes. The oceans have absorbed enough carbon dioxide to have already caused a slight increase in ocean acidification. This may be causing the carbonate structures of corals, algae, and marine plankton to dissolve. These organisms form the base of the food pyramid in the ocean.

CHEMICALS

A variety of chemicals from industrial and agricultural sources can cause water pollution. Examples include metals, solvents and oils, detergents, and pesticides. These can accumulate in fish and shellfish, poisoning the people, animals, and birds that eat them. On a square-foot basis, homeowners apply more chemicals to their lawns than farmers do to their fields. Each year, road runoff and other nonspill sources impart an amount of oil to the oceans that is more than 5 times greater than the *Exxon Valdez* spill—about 21 million barrels. Discharge of oily wastes and oil-contaminated ballast water and wash water are all significant sources of marine pollution. Drilling and extraction operations for oil and gas can also contaminate coastal waters and groundwater. The EPA estimates that about 100,000 gasoline storage tanks are leaking chemicals into groundwater. In Santa Monica, California, wells supplying half the city's water have been closed because of dangerously high levels of the gasoline additive MTBE. New evidence strongly suggests that components of crude oil, called polycyclic aromatic hydrocarbons (PAHs), persist in the marine environment for years and are toxic to marine life at concentrations in the low parts per billion (ppb) range. Chronic exposure to PAHs can affect the development of marine organisms, increase susceptibility to disease, and jeopardize normal reproductive cycles in many marine species.

Studies have shown that up to 90% of drug prescriptions pass through the human body unaltered. Animal farming operations that use growth hormones and antibiotics also send large quantities of these chemicals into the water. Most wastewater treatment facilities are not equipped to filter out personal care products, household products, or pharmaceuticals. As a result, a large portion of these chemicals pass directly into local waterways. Studies on the effects of these chemicals have discovered fragrance molecules inside fish tissues, ingredients from birth control pills causing gender-bending hormonal effects in frogs and fish, and the chemical nonylphenol, a remnant of detergent, disrupting fish reproduction and growth.

MICROBIOLOGICAL SOURCES

Disease-causing (pathogenic) microorganisms such as bacteria, viruses, and protozoa can result in swimmers getting sick and fish and shellfish becoming contaminated. Examples of waterborne diseases include cholera, typhoid, shigella, polio, meningitis, and hepatitis. In developing countries, an estimated 90% of the wastewater is discharged directly into rivers and streams without treatment. In the United States, 850 billion gallons (3 trillion L) of raw sewage are dumped into rivers, lakes, and bays each year by leaking sewer systems and inadequate combined sewer/storm systems that overflow during heavy rains. Leaking septic tanks and other sources of sewage can also cause groundwater and stream contamination. Beaches suffer the effects of water pollution from sewage. About 25% of all beaches in the United States annually have water pollution advisories or are closed each year due to bacterial buildup caused by sewage.

MINING

Mining causes water pollution in a number of ways. The mining process exposes heavy metals and sulfur compounds that were previously locked away in Earth. Rainwater leaches these compounds out of the exposed Earth, resulting in acid mine drainage and heavy-metal pollution that can continue long after the mining operations have ceased. Second, the action of rainwater on piles of mining waste (tailings) transfers pollution to freshwater supplies. In the case of gold mining, cyanide is intentionally poured on piles of mined rock (a leach heap) to extract the gold from the ore chemically. Some of the cyanide ultimately finds its way into nearby water. Additionally, huge pools of mining waste slurry are often stored behind containment dams that often leak or infiltrate ground water supplies. Fourth, mining companies in developing countries often dump mining waste directly into rivers or other bodies of water as a method of disposal.

The U.S. government in 2003 reclassified mining waste from mountaintop removal (a type of coal mining) so it could be dumped directly into valleys and burying streams altogether. The Iron Mountain mine in California has been closed since 1963 but continues to drain sulfuric acid and heavy metals into the Sacramento River. Experts say the pollution from this particular mine may continue for another 3,000 years.

NOISE

Many marine organisms, including marine mammals, sea turtles, and fish, use sound to communicate, navigate, and hunt. Because of oceanic water noise pollution caused by commercial shipping, military sonar, and recreational boating, some species may have a harder time hunting or detecting predators. They may also not being able to navigate properly.

NUTRIENTS

Phosphorus and nitrogen are necessary for plant growth and are plentiful in untreated wastewater. When added to lakes and streams, they can cause the growth of aquatic weeds that block waterways as well as algal blooms. If the source is from humans, it is called cultural eutrophication. Deposition of atmospheric nitrogen

(from nitrogen oxides) also causes nutrient-type water pollution. Nutrient pollution is also a problem in estuaries and deltas, where the runoff that was aggregated by watersheds is finally dumped at the mouths of major rivers.

OIL SPILLS

Oil is one of the world's main sources of energy, but because it is unevenly distributed worldwide, it must be transported by ship across oceans and by pipelines across land. This can result in accidents when transferring oil to vessels, when transporting oil, and when pipelines break, as well as when drilling for oil. Oil accidentally released into a marine environment drastically affects wildlife. The oil penetrates the feathers of seabirds, reducing the feathers' insulating ability and making the birds more vulnerable to temperature fluctuations and much less buoyant in the water. It also impairs seabirds' flight, and thus their abilities to forage and escape from predators. As they attempt to preen, birds typically ingest oil that covers their feathers, causing kidney and liver damage. This, along with the limited foraging ability, quickly results in dehydration. Marine mammals exposed to oil spills are affected in similar ways as seabirds. Because oil floats on top of water, less sunlight penetrates into the water, limiting the photosynthesis of marine plants and phytoplankton and affecting the food web in the ecosystem.

Recovering the oil is difficult and depends on many factors, including the type of oil spilled, the temperature of the water, and the types of shorelines and beaches involved. Methods for cleaning up include the use of microorganisms to break down oil; chemical agents, dispersants, sorbents, and detergents that act to disperse the oil, absorb it, or cause it to clump into gel-like agglomerations that sink; controlled burning; and booming, skimming, and/or vacuuming the oil from the surface or shoreline.

OXYGEN-DEPLETING SUBSTANCES

Biodegradable wastes are used as nutrients by bacteria and other microorganisms. Excessive biodegradable wastes can cause oxygen depletion in receiving waters. This can result in increases in anaerobic bacteria that produce ammonia, amines, sulfides, and methane (swamp gas) and decreases of aerobic organisms such as fish.

SUSPENDED MATTER

Suspended wastes eventually settle out of water and form silt or mud at the bottom. Toxic materials can also accumulate in the sediment and affect organisms throughout the food web. When forests are clear-cut, the root systems that previously held soil in place die and the sediment is free to run off into nearby streams, rivers, and lakes.

Plastics and other plastic-like substances (such as nylon from fishing nets and lines) can entangle fish, sea turtles, and marine mammals, causing injury and death. Certain types of plastic can break down into microparticles and become ingested by tiny marine organisms and move up the marine food chain. Plastic remains in the ecosystem and will continue to harm marine organisms far into the future.

THERMAL SOURCES

Produced by industry and power plants. Heat reduces the ability of water to hold oxygen and causes death to organisms that cannot tolerate heat and/or low oxygen

levels. Global warming is also imparting additional heat to the oceans, rivers, and streams with unknown consequences.

CASE STUDIES

Minamata disease: Twenty-seven tons of mercury-containing compounds from industrial processes were dumped into Minamata Bay in Japan between 1932 and 1968. The mercury collected in fish and shellfish caught from the bay. Symptoms included blurred vision, hearing loss, loss of muscular coordination, and reproductive disorders.

***Exxon Valdez* (1989):** In 1989, the oil tanker *Exxon Valdez* spilled 11 to 30 million gallons (42 to 110 million L) of crude oil into Prince William Sound, Alaska. As a result, 250,000 sea birds, 3,000 otters, 300 seals, 300 bald eagles, and 22 whales died along with billions of salmon and herring eggs. The oil also destroyed the majority of the plankton in the sound.

Gulf of Mexico Oil Spill (2010): In April 2010, a massive oil spill followed an explosion on the *Deepwater Horizon* offshore drilling rig operated by British Petroleum, becoming the most significant environmental disaster to occur in the United States. As the oil from the well site reached the Gulf coast, billions of dollars in damage was done to the Gulf of Mexico fishing industry, the tourism industry, and the habitat of hundreds of bird, fish, and other wildlife species.

Cultural Eutrophication

Cultural eutrophication is defined as the process whereby human activity increases the amount of nutrients entering surface waters. The two most important nutrients that cause cultural eutrophication are nitrates (NO_3^-) and phosphates (PO_4^{3-}) that come from fertilizer, sewage discharge, and animal wastes.

Nitrates are water soluble. Nitrates found in fertilizers can remain on fields and accumulate, leach into groundwater, end up in surface runoff, and/or volatize and enter the atmosphere where they contribute to acid precipitation. Nitrates cause nitrate poisoning in water supplies, reduce the effectiveness of hemoglobin, and may be responsible for worldwide declines in amphibians.

Phosphates are also a component of inorganic fertilizers. However, they are not water soluble and adhere to soil particles. Soil erosion contributes to the buildup of phosphates in water supplies. Phosphate levels in water supplies are 75% higher than they were during preindustrial times. Phosphate buildup is more damaging in freshwater systems. In contrast, nitrate pollution is more damaging in wetlands where nitrogen is the limiting factor.

Nitrates and phosphates are algal nutrients. Increased concentrations of these nutrients increase the carrying capacity of lakes and streams. Explosions in the amount of algae as a result of cultural eutrophication are called algal blooms. The steps involved in algal bloom include the following:

- Increased algae due to increased nitrate and/or phosphate concentrations result in decreased light penetration, killing off deeper plants and their supply of oxygen to water.

- Oxygen concentration decreases in the water due to the consequences of increased material for decomposers.
- Lower oxygen concentrations cause fish and other aquatic organisms to die and contaminate the water at a high rate.
- Decaying fish and algae produce toxins in the water.

Several methods can control cultural eutrophication. Planting vegetation (buffer zones) along streambeds slows erosion and absorbs some of the nutrients. Controlling the application and timing of applying fertilizer, controlling runoff from feedlots, and using biological controls such as denitrifying bacteria that convert nitrates into atmospheric nitrogen are other methods.

Groundwater Pollution

About 50% of the people in the United States depend on groundwater for their water supplies. In some countries, it may reach as high as 95%. Almost half of the water used for agriculture in the United States comes from groundwater. The Environmental Protection Agency (EPA) estimates that each day, 4.5 trillion liters of contaminated water seep into groundwater supplies in the United States. In the United States, 34 billion liters per year (60%) of the most hazardous liquid waste solvents, heavy metals, and radioactive materials are injected directly into deep groundwater via thousands of injection wells. Although the EPA requires that these effluents be injected below the deepest source of drinking water, some pollutants have already entered underground water supplies in Florida, Texas, Ohio, and Oklahoma.

Water entering an aquifer remains there for approximately 1,400 years compared with 16 days for water entering a river system. Once an aquifer is contaminated, it is practically impossible to remove the pollutants. For example, in Denver, Colorado, just 80 liters of organic solvents contaminated 4.5 trillion liters of groundwater. Initial cleanup of contaminated groundwater locations in the United States could cost up to $1 trillion over the next 30 years.

Maintaining Water Quality and Water Purification

DRINKING WATER TREATMENT METHODS

- **Adsorption**—Contaminants stick to the surface of granular or powdered activated charcoal.
- **Disinfection**—Chlorine, chloramines, chlorine dioxide, ozone, and UV radiation.
- **Filtration**—Removes clays, silts, natural organic matter, and precipitants from the treatment process. Filtration clarifies water and enhances the effectiveness of disinfection.
- **Flocculation-Sedimentation**—Process that combines small particles into larger particles that then settle out of the water as sediment. Alum, iron salts, or synthetic organic polymers are generally used to promote coagulation.
- **Ion Exchange**—Removes inorganic constituents. It can be used to remove arsenic, chromium, excess fluoride, nitrates, radium, and uranium.

WATER TREATMENT REMEDIATION TECHNOLOGIES

- **Adsorption/absorption**—Solutes concentrate at the surface of a sorbent (an absorbing surface), thereby reducing their concentration.

- **Aeration**—Bubbling air through water increases rates of oxidation.
- **Air stripping**—VOCs are separated from groundwater by exposing water to air (the VOCs evaporate due to their high vapor pressure).
- **Bioreactors**—Groundwater is acted upon by microorganisms.
- **Constructed wetlands**—Uses natural geochemical and biological processes that parallel natural wetlands. Also known as living machines.
- **Deep-well injection**—Uses injection wells to place treated or untreated liquid waste into geologic formations that do not pose a potential risk to groundwater.
- **Enhanced bioremediation**—The natural rate of bioremediation is enhanced by adding oxygen and nutrients into groundwater.
- **Fluid-vapor extraction**—A vacuum system is applied to low-permeable soil to remove liquids and gases.
- **Granulated activated carbon (GAC)**—Groundwater is pumped through a series of columns containing activated carbon.
- **Hot water or steam flushing**—Steam or hot water is forced into an aquifer to vaporize volatile contaminants and is then treated through fluid-vapor extraction.
- **In-well air stripping**—Air is injected into wells—the air picks up various contaminants, particularly VOCs. Vapors are drawn off by vapor extraction.
- **Ion exchange**—Involves exchange of one ion for another.
- **Phytoremediation**—Uses plants to remove contamination.
- **UV oxidation**—Uses ultraviolet light, ozone, or hydrogen peroxide to destroy microbiological contaminants.

Sewage Treatment/Septic Systems

Sewage treatment incorporates physical, chemical, and biological processes to remove contaminants from wastewater. There are three stages of wastewater treatment.

A septic system consists of a tank and a drain field. Wastewater enters the tank, where solids settle. Anaerobic digestion using bacteria treats the settled solids and reduces their volume. Excess liquid leaves the tank and moves through a pipe with holes in it to a leach field where the water then percolates into the soil.

Some pollutants, especially nitrogen, do not decompose in a septic system and may contaminate the groundwater. Approximately 25% of Americans rely on septic systems.

PRIMARY TREATMENT

Primary treatment is to reduce oils, grease, fats, sand, grit, and coarse solids. Specific steps include sand catchers, screens, and sedimentation. This is a physical method of cleaning.

SECONDARY TREATMENT

Secondary treatment is designed to degrade substantially the biological content of the sewage derived from human waste, food waste, soaps, and detergent. Specific steps include filters, activated sludge, filter (oxidizing) beds, trickling filter beds using plastic media, and secondary sedimentation. This is a biological method of cleaning.

TERTIARY TREATMENT

Tertiary treatment provides a final stage to raise the effluent quality to the standard required before it is discharged to the receiving environment (sea, river, lake, or ground). Specific steps may include sand filtration, lagooning, constructed wetlands, nutrient removal through biological or chemical precipitation, denitrification using bacteria, phosphorous removal using bacteria, microfiltration, and disinfection using UV light, chlorine, or ozone.

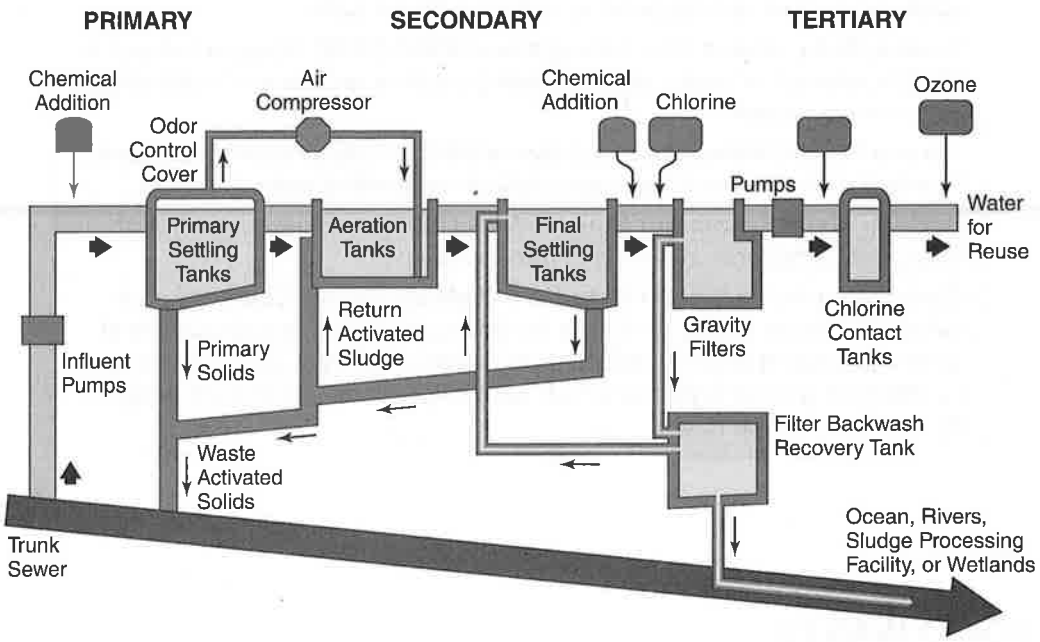


Figure 9.2 Sewage treatment plant

RELEVANT LAWS

Federal Water Pollution Control Act (1948): Created comprehensive programs for eliminating or reducing the pollution of interstate water and improving the sanitary condition of surface and underground water supplies.

Water Quality Act (1965): Established water purity standards with states retaining initial responsibility for water purity.

Clean Water Act (1972): Established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave the EPA the authority to implement pollution control programs such as setting wastewater standards for industry. The Clean Water Act also continued requirements to set water quality standards for all contaminants in surface waters. The act made it unlawful for any person to discharge any pollutant

TIP

Reference relevant laws in your essay answers whenever possible. They will substantiate your thoughts and provide a historical framework for the issue.

RELEVANT LAWS (continued)

from a point source into navigable waters unless a permit was obtained under its provisions. It also funded the construction of sewage treatment plants under the construction grants program and recognized the need for planning to address the critical problems posed by nonpoint source pollution.

Safe Drinking Water Act (1974): Established standards for safe drinking water in the United States.

Ocean Dumping Ban Act (1988): Made it unlawful for any person to dump or transport for the purpose of dumping sewage, sludge, or industrial wastes into the ocean.

Oil Spill Prevention and Liability Act (1990): Strengthened the EPA's ability to prevent and respond to catastrophic oil spills.

Source Water Assessment Program—SWAP (1996): Required states to identify sources of public drinking water supplies and assess susceptibility to contamination.

Source Water Protection Program—SWPP (1996): Encouraged states to adopt a community-based approach to preventing water pollution.

Surface Water Treatment Rule—SWTR (1996): Addressed control of microbial pathogens, including cryptosporidium.

Convention on Persistent Organic Pollutants (2001): Countries committed to reduce and/or eliminate the production, use, and/or release of twelve persistent organic pollutants of greatest concern (e.g., PCBs), and to establish a mechanism by which additional chemicals may be added to the Treaty in the future.

SOLID WASTE

Types of solid waste include:

- **Organic**—Kitchen wastes, vegetables, flowers, leaves, or fruits. Usually decomposes within 2 weeks. Wood can take 10 to 15 years to decompose.
- **Radioactive**—Spent fuel rods and smoke detectors. Radioactive wastes can take hundreds of thousands of years to decompose.
- **Recyclable**—Paper, glass, metals, and some plastics. Paper decomposes in 10 to 30 days. Glass does not decompose. Metals decompose in 100 to 500 years. Some plastics can take up to 1 million years to decompose.
- **Soiled**—Hospital wastes. Cotton and cloth can take 2 to 5 months to decompose.
- **Toxic**—Paints, chemicals, pesticides, and so on. Toxic wastes can take hundreds of years to decompose.

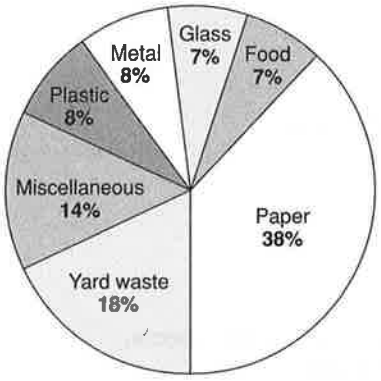


Figure 9.3 Amounts and types of municipal solid wastes (MSW) in the U.S.

Disposal and Reduction

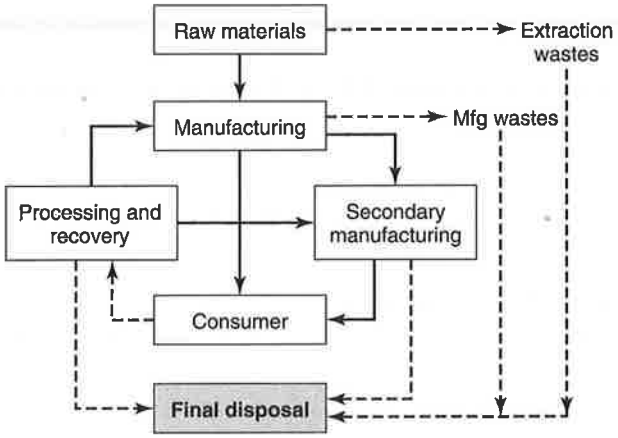


Figure 9.4 Solid waste flow diagram

BURNING, INCINERATION, OR ENERGY RECOVERY

Pros

- Heat can be used to supplement energy requirements.
- Reduces impact on landfills.
- Mass burning is inexpensive.
- What is left is 10% to 20% of original volume.
- U.S. incinerates 15% of its wastes.
- France, Japan, Sweden, and Switzerland incinerate > 40% of their wastes and use the heat to generate electricity.

Cons

- Air pollution including lead, mercury, NO_x, cadmium, SO_2, HCl, and dioxins.
- Sorting out batteries, plastics, etc. is expensive.
- No way of knowing toxic consequences.
- Ash is more concentrated with toxic materials.
- Initial costs of incinerators are high.
- Adds to acid precipitation and global warming.

COMPOSTING

Pros

- Creates nutrient-rich soil additive.
- Aids in water retention.
- Slows down soil erosion.
- No major toxic issues.

Cons

- Public reaction to odor, vermin, and insects.
- Not in my backyard (NIMBY).

REMANUFACTURING

Pros

- Recovers materials that would have been discarded.
- Beneficial to inner cities as an industry because material is available and jobs are needed.

Cons

- Toxic materials may be present (CFCs, heavy metals, toxic chemicals, and so on).

DETOXIFYING

Pros

- Reduces impact on the environment.

Cons

- Expensive.

EXPORTING

Pros

- Gets rid of problem immediately.
- Source of income for poor countries.

Cons

- Garbage imperialism or environmental racism.
- Long-term effects not known.
- Expensive to transport.

LAND DISPOSAL—SANITARY LANDFILLS

Pros

- Waste is covered each day with dirt to help prevent insects and rodents.
- Plastic liners, drainage systems, and other methods help control leaching material into groundwater.
- Geologic studies and environmental impact studies are performed prior to building.
- Collection of methane and use of fuel cells to supplement energy demand.

- Use of anaerobic methane generators reduces dependence on other energy sources.

Cons

- Rising land prices. Current costs are $1 million per hectare.
- Transportation costs to the landfill.
- High cost of running and monitoring landfill.
- Legal liability.
- Suitable areas are limited.
- NIMBY.
- Degradable plastics do not decompose completely.

LAND DISPOSAL—OPEN DUMPING

Pros

- Inexpensive.
- Provides a source of income to the poor by providing recyclable products to sell.

Cons

- Trash blows away in the wind.
- Vermin and disease.
- Leaching of toxic materials into the soil.
- Aesthetics.

OCEAN DUMPING

Pros

- Inexpensive.

Cons

- Debris floats to unintended areas.
- Marine organisms and food webs are impacted.
- Illegal in the United States.

RECYCLING

Pros

- Turns waste into an inexpensive resource.
- Reduces impact on landfills.
- Reduces need for raw materials and the costs associated with it.
- Reduces energy requirements to produce product. For example: recycling aluminum cuts energy use 95% and producing steel from scrap reduces energy requirements 75%.
- Reduces dependence on foreign oil.
- Reduces air and water pollution.
- Bottle bills provide economic incentive to recycle.

Cons

- Poor regulation.
- Fluctuations in market price.

- Throwaway packaging is more popular.
- Current policies and regulations favor extraction of raw materials. Energy, water, and raw materials are sold below real costs to stimulate new jobs and the economy.

REUSE

Pros

- Most efficient method of reclaiming materials.
- Industry models already in place—auto salvage yards, building materials, and so on.
- Refillable glass bottles can be reused 15 times.
- Cloth diapers do not impact landfills.

Cons

- Cost of collecting materials on a large scale is expensive.
- Cost of washing and decontaminating containers is expensive.
- Only when items are expensive and labor is cheap is reuse economical.

RELEVANT LAWS

Solid Waste Disposal Act (1965): First federal law that required environmentally sound methods for disposal of household, municipal, commercial, and industrial wastes.

Resource Conservation and Recovery Act (1976): Encouraged states to develop comprehensive plans to manage nonhazardous industrial solid and municipal wastes. Set criteria for municipal landfills and disposal facilities, and prohibited open dumping of solid wastes.

Toxic Substances Control Act (TOSCA) (1976): Gave the EPA the authority to track industrial chemicals produced within or imported into the United States. Allows the EPA to ban the manufacture or importation of chemicals that pose risks.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA—Superfund) (1980): Provided authority for the federal government to respond to releases or possible releases of hazardous substances that could threaten public health and/or the environment. Established rules for closed and abandoned hazardous waste sites. Established liability for corporations responsible for hazardous waste sites. Created a trust fund for cleanup if responsible parties for contaminated sites could not be found.

Nuclear Waste Policy Act (1982): Established federal authority to provide locations for permanent disposal of high-level radioactive wastes and required the operators of nuclear power plants to pay the costs of permanent disposal.

Marine Plastic Pollution Research and Control Act (1987): Discharge of plastics into water is prohibited. Food waste, paper, rags, glass, and metal cannot be discharged into navigable water or within 12 miles (19 km) of land.

RELEVANT LAWS (continued)

Medical Waste Tracking Act (1988): Required tracking systems, stringent management standards, packaging, and labeling of medical supplies.

Waste Reduction Act (1990): Requires the EPA to develop and coordinate a pollution prevention strategy and develop source reduction models. Requires owners and operators of manufacturing facilities to report annually on source reduction and recycling activities.

QUICK REVIEW CHECKLIST

- ☐ **Air Pollution**
  - ☐ major air pollutants
    - ☐ nitrogen dioxide
    - ☐ ozone
    - ☐ sulfur dioxide
    - ☐ suspended particulate matter (PM_{10})
    - ☐ volatile organic compounds (VOCs)
  - ☐ measurement units
  - ☐ smog
    - ☐ formation of industrial smog
    - ☐ formation of photochemical smog
  - ☐ acid deposition
    - ☐ causes and effects
  - ☐ heat islands
  - ☐ temperature inversions
  - ☐ indoor air pollution
  - ☐ remediation and reduction strategies
  - ☐ relevant laws and protocols
    - ☐ Air Pollution Control Act (1955)
    - ☐ Clean Air Act (1963)
    - ☐ National Environmental Policy Act (1969)
    - ☐ Clean Air Act (1970)
    - ☐ Montreal Protocol (1989)
    - ☐ Clean Air Act (1990)
    - ☐ Pollution Prevention Act (1990)
    - ☐ Kyoto Protocol

QUICK REVIEW CHECKLIST (continued)

- ☐ **Noise Pollution**
  - ☐ causes
  - ☐ effects
  - ☐ control measures
  - ☐ Noise Control Act (1972)
- ☐ **Water Pollution**
  - ☐ sources
    - ☐ air pollution
    - ☐ chemicals
    - ☐ microbiological
    - ☐ mining
    - ☐ noise
    - ☐ nutrients
    - ☐ oxygen-depleting substances
    - ☐ suspended matter
    - ☐ thermal sources
  - ☐ Minamata disease
  - ☐ *Exxon Valdez* (1989)
- ☐ **Cultural Eutrophication**
- ☐ **Groundwater Pollution**
- ☐ **Maintaining Water Quality and Water Purification**
  - ☐ drinking water treatment methods
  - ☐ water treatment remediation technologies
- ☐ **Sewage Treatment/Septic Systems**
  - ☐ primary treatment
  - ☐ secondary treatment
  - ☐ tertiary treatment
- ☐ **Relevant Laws**
  - ☐ Federal Water Pollution Control Act (1948)
  - ☐ Water Quality Act (1965)
  - ☐ Clean Water Act (1972)
  - ☐ Safe Drinking Water Act (1974)
  - ☐ Ocean Dumping Ban Act (1988)
  - ☐ Oil Spill Prevention and Liability Act (1990)
  - ☐ Source Water Assessment Program SWAP (1966)
  - ☐ Source Water Protection Program SWPP (1996)
  - ☐ Surface Water Treatment Rule SWTR (1996)

QUICK REVIEW CHECKLIST (continued)

- ☐ **Solid Wastes**
  - ☐ different types
    - ☐ organic
    - ☐ radioactive
    - ☐ recyclable
    - ☐ soiled
    - ☐ toxic
  - ☐ amounts and type of MSW
  - ☐ disposal and reduction methods
    - ☐ incineration
    - ☐ composting
    - ☐ remanufacturing
    - ☐ detoxifying
    - ☐ exporting
    - ☐ land disposal—sanitary landfills
    - ☐ land disposal—open dumping
    - ☐ ocean dumping
    - ☐ recycling
    - ☐ reuse
    - ☐ solid waste flow diagram

- ☐ **Relevant Laws**
  - ☐ Solid Waste Disposal Act (1965)
  - ☐ Resource Conservation and Recovery Act (1976)
  - ☐ Toxic Substances Control Act (TOSCA) (1976)
  - ☐ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA-Superfund) (1980)
  - ☐ Nuclear Waste Policy Act (1982)
  - ☐ Marine Plastic Pollution Research and Control Act (1987)
  - ☐ Medical Waste Tracking Act (1988)
  - ☐ Waste Reduction Act (1990)

MULTIPLE-CHOICE QUESTIONS

1. _____contributes to the formation of _____ and thereby compounds the problem of _____.

   (A) ozone, carbon dioxide, acid rain
   (B) carbon dioxide, carbon monoxide, ozone depletion
   (C) sulfur dioxide, acid deposition, global warming
   (D) nitrous oxide, ozone, industrial smog
   (E) nitric oxide, ozone, photochemical smog

2. Photochemical smog does NOT require the presence of

   (A) nitrogen oxides
   (B) ultraviolet radiation
   (C) peroxyacyl nitrates
   (D) volatile organic compounds
   (E) ozone

3. Which of the following is a natural component of the atmosphere, comprises about 0.036% by volume of the atmosphere and is produced by the decay of vegetation, volcanic eruptions, exhalation of animals, burning of fossil fuels and deforestation?

   (A) Carbon monoxide
   (B) Carbon dioxide
   (C) Nitrous oxide
   (D) Nitrogen dioxide
   (E) Methane

4. Which of the following steps is NOT involved in the production of industrial smog?

   (A) $C + O_2 \rightarrow CO_2$
   (B) $C + O_2 \rightarrow CO$
   (C) $S + O_2 \rightarrow SO_2$
   (D) $NO_2 \rightarrow NO + O$
   (E) $SO_2 + O_2 \rightarrow SO_3$

5. Household water is most likely to be contaminated with radon in homes that

   (A) are served by public water systems that use a groundwater source
   (B) are served by public water systems that use a surface water source
   (C) have private wells
   (D) use bottled water
   (E) are served by water agencies that use ozone to disinfect the water

6. Which reaction is NOT involved in the formation of acid deposition?

   (A) $O_3 + C_xH_y \rightarrow PANS$
   (B) $SO_2 + H_2O \rightarrow H_2SO_3$
   (C) $H_2SO_3 + \frac{1}{2}O_2 \rightarrow H_2SO_4$
   (D) $NO + \rightarrow \frac{1}{2}O_2 \rightarrow NO_2$
   (E) $2NO_2^{\cdot} + H_2O \rightarrow HNO_2 + HNO_3$

7. Normal rainfall has a pH of about

   (A) 2.3
   (B) 5.6
   (C) 7.0
   (D) 7.6
   (E) 8.3

8. According to the Environmental Protection Agency, about _____ of all commercial buildings in the United States are classified as sick.

   (A) 5%
   (B) 15%
   (C) 50%
   (D) 75%
   (E) 100%

9. In developing countries, the most likely cause of respiratory disease would be

   (A) photochemical smog
   (B) industrial smog
   (C) smoking
   (D) PM_{10}
   (E) asbestos

10. Humans LEAST susceptible to the effects of air pollution are

    (A) newborns
    (B) children between the age of 2 and 10
    (C) teenagers
    (D) adult males
    (E) the elderly

11. Acid precipitation, leaching out the metal _____ , causes fish and other aquatic organisms to die from acid shock.

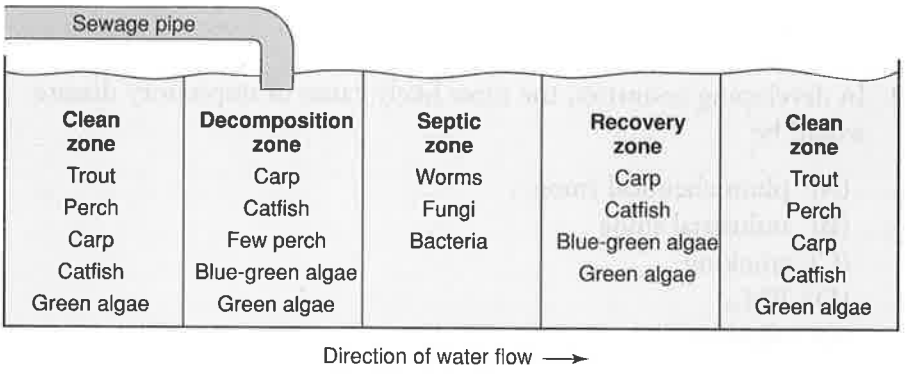
    (A) Al
    (B) Pb
    (C) Hg
    (D) Cd
    (E) Fe

12. Which pollutant best illustrates the effectiveness of legislation?

    (A) NO_2
    (B) SO_2
    (C) CO_2
    (D) O_3
    (E) Pb

13. The diagram below shows the range of organisms found within certain sections of a river in an industrial area. Which section of the river most likely has the LOWEST level of dissolved oxygen?

Effects of Sewage Discharge in a River
Organisms commonly found in discharge zone



(A) Clean zone
(B) Decomposition zone
(C) Septic zone
(D) Recovery zone
(E) None of the above

14. Which one of the following statements is TRUE?

(A) The United States generates approximately 230 million tons of municipal solid waste a year, about 4.6 pounds per person per day.
(B) Food waste is the third largest component of generated waste (after yard waste and corrugated boxes) and the second largest component of discarded waste.
(C) It takes 3 to 12 months to produce compost, depending on the type of waste.
(D) The average American college student produces 640 pounds of solid waste each year, including 500 disposable cups and 320 pounds of paper.
(E) All statements are true.

15. The major source of solid waste in the United States comes from what source?

(A) Homes
(B) Factories
(C) Agriculture
(D) Petroleum refining
(E) Mining wastes

16. What is the largest type of domestic solid waste in the United States?

(A) Yard wastes
(B) Paper
(C) Plastic
(D) Glass
(E) Metal

17. Which of the following is most readily recyclable?

(A) Plastic
(B) Paper
(C) Metal
(D) Glass
(E) All are equally and readily recyclable

18. Which of the following statements is TRUE?

(A) Recycling is more expensive than trash collection and disposal.
(B) Landfills and incinerators are more cost effective and environmentally sound than recycling options.
(C) The marketplace works best in solving solid waste management problems; no public sector intervention is needed.
(D) Landfills are significant job generators for rural communities.
(E) None of the above are true.

19. In the 1970s, houses were built over a toxic chemical waste disposal site. This case study is known as

(A) Love Canal
(B) Bet Trang
(C) Bhopal
(D) Brownfield
(E) Chernobyl

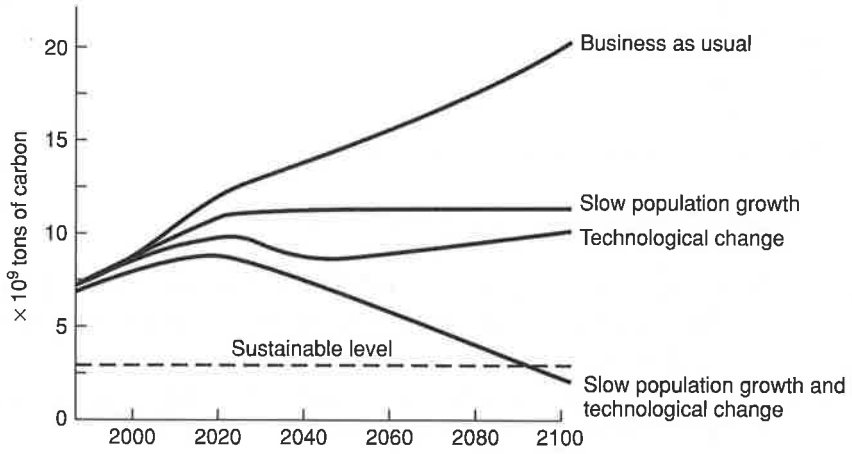
20. Which of the following methods of handling solid wastes is against the law in the United States?

(A) Incineration
(B) Dumping it in open landfills
(C) Burying it underground
(D) Exporting the material to foreign countries
(E) Dumping the material in the open ocean

FREE-RESPONSE QUESTION

By Dr. Ian Kelleher
Brooks School
North Andover, MA

(a) Study the following graph, which shows projected trends in annual carbon dioxide emissions, and then answer the following questions.



(i) In the "business as usual" model, what factors do you think might contribute to the increase in carbon dioxide emissions?
(ii) Given the shape of the graph, what do you think is meant in this case by "technological change"?
(iii) What is meant by a "sustainable level" of carbon dioxide emissions? According to these predictions, what needs to happen for this level to be brought about?

(b) Use the example of acid deposition to illustrate the difference between remediation and alleviation of an environmental problem.

(c) Look at the graph of CFC production and account for the trends you observe.